A STATISTICAL VALIDATION OF CEPHALOMETRIC PREDICTION

by

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Submitted in partial fulfillment of the requirements

for the Degree of Master of Science

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CASE WESTERN RESERVE UNIVERSITY

June 9, 1971

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Abstract

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For many years the orthodontic profession has been striving to perfect a technique whereby the amount of growth for a given individual from one chronological period to another may be accurately predicted.

The purpose of this investigation was to evaluate the predictive significance of regression equations or correlation coefficients derived from growth studies by Björk and Palling (1955), Meredith (1958), Johnston (1968), and Maj and Luzi (1964). The regression equations and correlation coefficients (Meredith) were validated by comparing or applying them to a different sample having the same age-range and sex as that from which they were calculated.

The sample was obtained from lateral roentgenographic cephalograms from the Bolton Study at Case Western Reserve University.

A sample of fifty subjects, each having two lateral cephalograms in occlusion taken at the desired ages, was utilized for each group except Björk and Palling's, which consisted of twenty subjects.

Tracings were made in pencil (3H) on .003 inch frosted acetate. Linear measurements were made with pointed dial vernier calipers, and were read to the nearest hundredth of a millimeter. Angular measurements, to the nearest tenth of a degree, were obtained with the aid of a drafting machine. Area measurements, when necessary, were executed with a compensating polar planimeter.

After a review of the resultant data, the following conclusions were formulated.

1. Björk and Palling's prediction equations do not provide sufficiently accurate predictions for the more important craniofacial measurements to warrant widespread use. Furthermore, the age span from twelve to twenty year old males severly hinders the clinical applicability of these equations.

2. The multiple linear regression equations of Johnston, which are based upon measures involving the occlusal plane, are unreliable; however, the

measures based upon the palatal plane are fairly reliable and more useful than Björk and Palling's equations, inasmuch as Johnston's equations cover five age groups from four to thirteen for both males and females.

3. The equations published by Johnston, however, are not felt to be sufficiently accurate to constitute a clinically useful prediction scheme.

4. The prediction scheme of Maj and Luzi was extremely unreliable and of little clinical significance. The accuracy, however, might have been increased somewhat had the authors calculated absolute rather than relative increments in mandibular length.

5. Meredith's correlation coefficients augured no clinically useful relationships between head length, nose depth, or face height at age five and absolute or relative increase in the same measure during the ensuing six years.

6. Contemporary methods of cephalometric prediction are incapable of accurately estimating clinically meaningful changes in the craniofacial complex which occur only as a consequence of growth.

7. Predictable changes in the craniofacial complex occuring as a result of growth are so slight in comparison with changes wrought by orthodontic treatment and inherent errors in the cephalometric technique that the prediction of growth changes, in and of themselves, seems to be a fruitless endeavor.

8. The use of simple regression equations yields different measures than an assumption of mean change; however, the predictions are no more accurate (confidence intervals remain the same).

ACKNOWLEDGMENTS

This investigation was conducted under the direction of Dr. Lysle E. Johnston, Jr., Assistant Professor and Chairman of the Department of Orthodontics, School of Dentistry, Case Western Reserve University. I wish to express my sincere thanks for his invaluable counsel, assistance, patience, and criticism during the preparation of this thesis.

I wish to extend my sincere thanks to Dr. B. Holly Broadbent, Jr., Associate Professor of Dentofacial Morphology, School of Dentistry, Case Western Reserve University, for his advice, criticism, and generous use of the Bolton Study records.

To Dr. Joel Wisotzky, Professor of Oral Biology and Medicine and Director of Dental Research, School of Dentistry, Case Western Reserve University, I wish to express my gratitude for his criticism and assistance in completing the statistical portions of this study.

I also wish to express my appreciation to Mr. William Golden, Research Associate, School of Dentistry, Case Western Reserve University, for his help during the tracing facets of this study and Mrs. Ida Morrison, Technical Secretary for her

assistance in obtaining the Bolton Study records.

To Miss Nancy Kukla, I wish to extend my appreciation for the time and effort spent in typing this thesis.

Dedication

To my parents for reasons that
would more than fill this page.

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I. INTRODUCTION

Orthodontic diagnosis and treatment ideally should be dependent upon and tailored to the form and growth of the human face. For many years the orthodontic profession has been striving to perfect a technique whereby the amount of growth for a given individual, from one chronological period to another, may be accurately predicted.

Specific studies by Björk and Palling, Meredith, Johnston, Maj and Luzi, and others have dealt with this problem of growth prediction; however, the regression or prediction equations derived from some of these studies (via least squares regression) are based upon relatively small, isolated, specific samples. Thus, there is no reason to believe that these equations can be used elsewhere, unless their predictive significance has been validated.

It will be the purpose of this paper to compare correlation coefficients (Meredith, 1958) and to examine the predictive significance of regression equations derived from growth studies by Björk and Palling (1955), Maj and Luzi (1964), and Johnston (1968). The regression equations and correlation coefficients will be tested by applying or comparing them to a

different sample having the same age-range and sex as that from which they were calculated. This very necessary step--validation--must be undertaken before any given equation can be accepted and universally applied by members of the orthodontic profession. A diminution in predictive accuracy is, of course, to be expected, but is it statistically so great as to render comparison from one growth study to another meaningless, in spite of identical age-ranges?

II. REVIEW OF THE LITERATURE

A review of the orthodontic literature concerning cephalometric prediction will record the profession's changing attitude toward the concept of variation, both individual and group.

In 1931, Broadbent introduced a roentgenographic method by which standardized serial roentgenograms of the growing face could be obtained. The orthodontic profession now possessed a method by which accurate investigation of facial growth could be accomplished. Then in 1937, Broadbent presented his paper entitled, "Normal Developmental Growth of the Face", in which he illustrated an apparently orderly growth pattern of the human face. This article led many members of the orthodontic profession to believe there was no change in the proportion of the growing face.

Then in 1941, Brodie published his thesis, "On the Growth Pattern of the Human Head From the Third Month to the Eighth Year of Life". Longitudinal data obtained from lateral cephalograms of a sample of twenty-one males provided the basis for his conclusion (p. 262):

From all of the evidence it seems that the morpho-

> genetic pattern of the human skull is established at a very early age and that once attained it does not change.

This thesis did much to discredit individual variation and in 1953, Brodie presented a continuation of his 1941 thesis in which he examined children from the ages of eight to seventeen years. In this study Brodie noted many individual changes in pattern, but still concluded that (p. 157):

> Findings such as these would be very discouraging were it not for the one fact, that is, the marked consistency and stability of the individual pattern.

Brodie enunciated his "pattern concept" most succinctly in an article published in 1946 (p. 87):

> The growth of the pattern is proportional. This means that the disharmony is present from before birth: it becomes neither better nor worse. It cannot be changed by treatment.

If the individual pattern is constant and stable as stated by Brodie, then growth prediction is meaningless, because the relative proportions of the face will not change and the orthodontist must work with what he has available.

The reversal of this concept began in 1947 when Björk, in a cross-sectional cephalometric study of 322 males at twelve years of age and 281 males at twenty years of age, concluded that (p. 131):

> The degree of prognathism of both jaws increases somewhat during the growth period, that of the lower jaw relatively more than the upper jaw, thus straightening the facial profile.

In a follow-up longitudinal study published in 1951, Björk reexamined at age twenty the facial profiles of the 322 twelve year old males from his 1947 study. He concluded that (p. 202):

> This wide variation in the growth type of the facial structure expresses itself as an individually increased or reduced prognathism of one or both jaws.

In 1948, Downs introduced his classical article entitled, "Variations in Facial Relationships: Their Significance in Treatment and Prognosis", in which he stated (p. 827):

> One studying cephalometric roentgenograms soon becomes conscious that they show considerable difference in general pattern.

Other investigators agreed that there seemed to be a change in growth pattern. Lande (1952) found a straightening of the profile due to an increase in mandibular prognathism. Coben (1955) in a longitudinal study concluded that (p. 433):

> When one considers the variation seen in the cranial base and the variation in every structure composing the dento-facial complex, it would seem that there could not be any rigid combination of factors associated with any particular type of malocclusion.

Additional longitudinal studies soon followed; Nanda

(1955) found after measuring the rates of growth of several facial components that (p. 672):

> When the finer analysis by means of relative rates is made, the differential rates of growth are sufficient from one dimension to another to change the form of the face over and beyond the basic age change in facial form common to all persons.

Pelton and Elsasser (1955) in a longitudinal study found (p. 206):

> There is an increase in facial prognathism with advancing age. With the maxilla coming forward to a greater degree than the mandible, it is reasoned that the convexity of the facial profile increases with age in both sexes.

Björk and Palling (1955) published longitudinal cephalometric data based on a sample of 243 males. Björk's previous articles in 1951 and 1953 dealt mainly with facial profile or the occlusion of the teeth during the growth and development of the individual, but the data published in 1955 concerned age changes (twelve to twenty years of age) in jaw relationships, alveolar prognathism and incisal inclination. The findings, which are summarized in Table 1, also include the results of a study Björk published in 1953 on age changes in overjet and sagittal jaw relation. A definition of the landmarks and planes employed by Björk and Palling in their study may be found in Appendix II.

TABLE 1

SUMMARY OF BJÖRK AND PALLING (1955)

Variable	Mean 12	SD 12	Mean 20	SD 20	B 12/20	r 12/20
I. Alveolar prognathy, upper						
1. pr-n-ss	2.3	0.9	2.3	1.0	0.71	0.65
II. Alveolar prognathy, lower						
2. id-n-pg	1.2	1.4	0.9	1.7	0.98	0.83
3. CL/ML	68.2	5.4	65.4	6.4	1.00	0.86
III. Incisal inclination, upper						
4. IL_s/OL	57.8	4.6	60.3	4.7	0.68	0.66
5. IL_s/NL	110.5	6.0	111.2	6.4	0.80	0.76
IV. Incisal inclination, lower						
6. IL_i/OL	70.3	6.3	69.8	6.6	0.71	0.68
7. IL_i/ML	92.1	6.7	90.5	7.2	0.89	0.83
V. Sagittal jaw relation						
8. ss-n-pg	2.5	2.6	1.3	3.0	1.00	0.87
9. (ar-pgn)-(ar-ss)[a]	19.9	4.0	27.8	4.9	1.06	0.87
Sagittal apical base relation						
10. ss-n-sm	3.4	2.3	2.7	2.6	0.77	0.86
11. OL/ss-sm[b]	92.6	4.5	91.5	4.6	0.89	0.86
12. (ar-sm)-(ar-ss)[a]	8.0	3.2	12.5	4.0	1.09	0.87

[a]Difference in length of facial radii.

[b]Inferior-posterior angle between occlusal line (OL) and a profile line through ss and sm.

TABLE 1--Continued

Variable	Mean 12	SD 12	Mean 20	SD 20	B 12/20	r 12/20
Profile angle						
13. n-ss-pg	173.8	5.3	177.7	6.1	1.00	0.88
Prognathic angles						
14. s-n-ss	81.3	3.3	82.0	3.7	1.00	0.91
15. s-n-sm	77.8	3.3	79.3	3.7	1.00	0.90
16. s-n-pg	78.8	3.3	80.7	3.9	1.00	0.89
Inclination of upper to lower incisors						
17. IL_s/IL_i	128.1	8.3	130.1	9.0	0.77	0.72
Facial radii						
18. ar-ss	83.4	4.0	91.4	4.6	1.00	0.91
19. ar-sm	91.4	4.5	103.0	5.4	1.00	0.87
20. ar-pgn	103.3	5.1	119.2	6.0	1.00	0.86
Jaws						
21. pm-ss	48.1	2.6	52.7	2.9	0.92	0.81
22. pm to NSP	13.9	2.7	13.8	3.3	1.05	0.86
23. pgn-cd	110.4	4.9	127.6	5.9	0.93	0.77

Determinations no.: 9, 12, 18, 19, 20, 21, 22, 23 are expressed in millimeters, all others in degrees.

Björk (1955 and 1963) also presented findings from metallic implant studies, which provided more evidence for the variability of the individual pattern. The orthodontic profession began to realize that the

individual pattern of growth does indeed change and the changes which occur may be significant enough to effect clinical treatment; the search for methods to predict these changes in individual growth pattern began. Most often these prediction studies have been based upon longitudinal data and correlation coefficients or regression equations.

Sarnas (1956) conducted a pilot study to assess the possible influence of age-range, dental maturation, sex and variance on correlation analysis. He concluded that (p. 162):

> A tendency to lower levels of significance was observed in the single age and dental maturation groups in comparison with the total material group. No difference with regard to sex was noticed.

Meredith (1958 and 1959) presented the results (correlation coefficients only) of studies, which dealt in part, with the prediction of certain craniofacial dimensions. His findings are summarized in Table 2 and represent the results of a longitudinal study of males from the ages of five to eleven.

The most concentrated attempt to apply growth prediction to the practice of orthodontics has been that of Ricketts. In a series of articles (1957, 1960, 1961) he described a technique of "cephalometric

TABLE 2

SUMMARY OF MEREDITH'S CRANIOFACIAL CORRELATIONS

Size-Gain (mm)

x	y	r	Sample Size N
Head Length Age 5	Increase between 5 & 11	-0.09	100
Face Depth Age 5 NA-ANS	Increase between 5 & 11	0.13	57
Nose Height Age 5	Increase between 5 & 11	-0.03	57

Size-Gain (%Increase)

x	y	r	Sample Size N
Head Length Age 5	Increase between 5 & 11	-0.28	100
Face Depth Age 5 NA-ANS	Increase between 5 & 11	0.02	57
Nose Height Age 5	Increase between 5 & 11	-0.35	57

synthesis" which he characterized as, "An estimation of prediction of changes in the skeletal framework in conjunction with the movement of teeth." Considerable emphasis is placed by Ricketts upon morphological characteristics, such as: ramus height, width of symphysis, etc., which are supposed to effect the pattern of growth. Thus, by a simultaneous consideration of the morphological pattern and the effects of

treatment, the skeletal growth pattern presumably may be established. However, Balbach (1969), using Ricketts' measures representing mandibular morphology, could find no characteristics upon which an accurate prediction of future mandibular position could be made.

Johnston (1968) evaluated cephalometric prediction and then raised the following valid objections to Ricketts' "growth prediction" system (p. 300):

> 1. There is little evidence as to the exact significance of each of the many variables employed.
>
> 2. There is little reason to believe that these numerous variables are not, to a greater or lesser extent, redundant.
>
> 3. There are no objective rules available for the use of these variables.
>
> 4. Estimates of confidence intervals or of prediction efficiency for a consecutive, nonorthodontic series are not available.

Also included in Johnston's report are multiple regression equations for males for future size (Table 3). For a definition of the measures employed by Johnston see Appendix IV.

Johnston's findings tended to agree with those of Burstone (1963) who considered many of the problems involved in cephalometric growth prediction and emphasized that one must evaluate carefully the level and rate of maturation using such characteristics as dental

TABLE 3

JOHNSTON'S MULTIPLE REGRESSION EQUATIONS, R, R^2, AND S.E.Y.

MALES

	$y = a + (b_1 \cdot x_1) + (b_2 \cdot x_2) + (b_3 \cdot x_3) + (b_4 \cdot x_4)$									R	R_2	S.E.Y.
Future Size	$\underline{A}/\overline{B}$	12.48	0.84	$\underline{A}/\overline{B}$	-1.49	Sp/Pal.				.785	.616	2.11
	A/B	-0.07	0.88	A/B	0.32	Cp-S	-0.11	∠ Ptyg.		.811	.657	1.49
	e/e	0.06	0.76	e/e						.742	.550	1.19
	∠ Z	3.12	0.81	∠ Z						.792	.628	1.87
	Prog.	0.89	1.05	Prog.						.887	.787	1.60

age, skeletal age, sex, sexual development, body type, height, and genetic factors. However, Gianelly, in a recent study (1970), found that facial proportions show little age or sex variation between the age of eight and thirteen years and concluded that (p. 501):

> There appears to be little need for separate age and sex cephalometric norms for patients between eight and thirteen years of age.

Burstone concluded his 1963 study by stating that (p. 913):

> A growth prediction of the face implies that not only have we gained an understanding of the developmental level of the child whom we are treating, but that we also have evaluated his rate of development in comparison to his peers.

The importance of growth prediction was reiterated in 1968 by Hixon, (p. 130):

> When individual variability in growth is coupled with the relative inability of orthodontic forces to alter the size of the facial skeleton in clinically meaningful terms, the ability to predict facial growth becomes of importance.

He concluded his study by stating, (p. 137):

> Cephalometric measurements serve to describe the patient as he is, but do not enhance one's ability to forecast individual growth change. Thus, the best available estimate of an adult facial dimension of a given child is to use the dimension presented by the child and add to that the remaining average growth for the group.

During this same period many other articles were introduced concerning dentofacial growth in general and mandibular growth in particular.

Merow (1962) presented the results of an appraisal of facial growth and concluded that (p. 212):

> The horizontal proportion of the upper face tended to remain stable, while the lower face demonstrated an increase.

Then Maj and Luzi (1964) demonstrated a significant relation between the magnitude of the gonial angle at nine years of age and the relative increments of mandibular growth from nine to thirteen years. The above relationship was used by the authors to predict the amount of mandibular growth in length between nine and thirteen years, on the basis of the gonial angle. The formula that gives the predictable amount of relative increment in mandibular length on the basis of values of the gonial angle is as follows:

A. when x is $> 125.85°$

$$y = 9.392 + 0.329\ (x - 125.85)$$

B. when x is $< 125.85°$

$$y = 9.392 + 0.329\ (125.85 - x)$$

where y = relative increment of mandibular length from nine to thirteen years

x = measure in degrees of the gonial angle at nine years of age

Maj and Luzi based this study upon a sample size of twenty-eight and stated, (p. 230):

> . . . it is our sincere hope that this paper will stimulate orthodontists who deal with longitudinal roentgenographic material covering the time period considered in our research, to check the validity of our data.

In 1969, Balbach studied the relationship between mandibular morphology and its future position and found no evidence supporting the hypothesis (p. 40):

> . . . that individual mandibular characteristics provide information upon which to base an accurate prediction of changes in the occlusal position of the mandible.

In spite of these findings Ødegaard in 1970 presented the results of his research, in which he employed metallic implants to study mandibular growth. In this study he gives regression equations demonstrating the relationship between angle alpha (angle between the condylar growth line and the mandibular plane) and mean condylar growth.

Ødegaard concluded his study by stating that (p. 156):

> When a prediction of mandibular growth is to be made, this must be based upon mandibular morphology and not upon the position of the mandible in space.

Apparently, then, a prediction of mandibular growth cannot be based upon mandibular morphology or the position of the mandible in space.

Currently the concept of the variability of the individual pattern is accepted by most orthodontists. The changes in growth pattern which do occur may be significantly large to effect the outcome of orthodontic therapy; thus, the desirability of a method by which one can predict any changes in the individual growth pattern. The growth studies of Björk and Palling (1955), Meredith (1958), Maj and Luzi (1964), and Johnston (1968), represent an attempt to predict changes in the individual growth pattern. However, can the changes observed in one sample and the regression equations derived from that sample be universally and accurately applied to another? Since a regression equation is derived by a curve fitting procedure, it is subject to random error and quite possibly cannot be applied to another population; that is unless properly validated. Thus, it is necessary to validate prior to the catholic application of a given equation.

III. MATERIALS

Source

The linear regression equations or correlation coefficients validated in this investigation were obtained from reports by the following authors:

1. Björk, Arne and Palling, Mogens: Adolescent age changes in sagittal jaw relation, alveolar prognathy and incisal inclination. Acta Odont. Scand. 12: 201-232, Feb. 1955.

2. Johnston, Lysle E.: A statistical evaluation of cephalometric prediction. Angle Orthodont., 38: 284-304, Oct. 1968.

3. Maj, G. and Luzi, C.: Longitudinal study of mandibular growth between nine and thirteen years as a basis for an attempt of its prediction. Angle Orthodont., 34: 220-230, July 1964.

4. Meredith, H. V. and Meredith, E. M.: Concomitant variation of measures of body size on boys five years of age and measures of growth rate for the ensuing sexenium. Growth, 22: 1-8, Mar. 1958.

Sample

The sample to which the regression equations of Björk and Palling, Johnston, Maj and Luzi, and the correlation coefficients of Meredith were applied was obtained from lateral roentgenographic cephalograms of the Bolton Study at Case Western Reserve University. In order to apply the various equations to a sample having identical age-range and sex as the

original study, from which the regression equations and/or correlation coefficients were derived, the sample was subdivided into the following four groups:

Group A--Males--Ages twelve to twenty--to evaluate equations of Björk and Palling.

Group B--Males--Ages seven to twelve--to evaluate equations of Johnston.

Group C--Males and Females--Ages nine to thirteen--to evaluate equations of Maj and Luzi.

Group D--Males--Ages five to eleven--to evaluate correlation coefficients of Meredith.

A sample of fifty subjects, each having two lateral cephalograms in occlusion taken at the desired ages, was utilized for each group except for Group A, which consisted of twenty subjects.

The cephalometric subjects chosen were subject to the following qualifications:

1. The radiographs had to be of adequate quality to insure accurate tracing of landmarks.

2. All children selected had not been treated orthodontically.

3. A given age, X years, was assigned to cephalograms over the range, X years - three months to X years + three months.

4. The selection was in no way predicated upon any characteristic of the occlusion.

IV. METHOD

Technical Details

The lateral roentgenographic cephalograms used in this study were obtained with a Broadbent-Bolton roentgenographic cephalometer. The source-film distance was five feet. The target-film distance, however, was variable and the resulting enlargement averaged 5.6%. Inasmuch as the variance was only .006, it was not thought necessary to compensate for the varying target-film distance. All tracings were made in pencil (3H) on .003 inch frosted acetate. Linear measurements were obtained with pointed dial vernier calipers,[1] and were read to the nearest hundredth millimeter. Angular measurements, to the nearest tenth of a degree, were obtained with the aid of a drafting machine.[2] Area measurements, when necessary, were executed with a compensating polar planimeter[3] according to a preselected scale, 100 sq. cm. = 100 vernier units.

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[1]Helios Dial Calipers.

[2]Vemco--Model 3300.

[3]Kent--#10933.

Analytical Methods

As outlined previously, the regression equations of Björk and Palling, Johnston, Maj and Luzi, and the correlation coefficients of Meredith will be validated by applying or comparing them to a different sample having identical age-range and sex as the original sample. This very necessary step must be undertaken, because there is no reason to believe that these regression equations or correlation coefficients can be applied to another sample with any degree of accuracy. The measures of Meredith, head length, face depth, and nose height, are clinically useless; however, they are included in this study since they are based on a sample remarkably similar to that obtained from the Bolton Study at Case Western Reserve University. Hence, they are American born, white boys of predominantly northwest European ancestry, and are considerably above average socioeconomically.

The statistic used most frequently by the previously mentioned authors is the coefficient of correlation (r_{xy}), the magnitude of which estimates the extent of linear correlation between two variables (x and y), such that +1.0 is a perfect positive correlation, -1.0 is a perfect negative correlation, and 0 indicates independence. If there is a significant

correlation then the data may be used to calculate a regression equation (least squares regression). Björk and Palling, Johnston, and Maj and Luzi did just that, but Meredith published only his correlation coefficients. Since the regression equations presented by Björk and Palling, Johnston, and Maj and Luzi deal with predicting measurements at later age by employing measurements taken at an earlier age, the predictive significance of these equations may be validated by means of correlation coefficients, coefficients of determination, index of forecasting efficiency, and standard error of estimate for the relationship between actual and predicted values for each individual in the sample.

Björk and Palling

Björk and Palling's data (1955, Appendix I) contains means and standard deviations at twelve and twenty years for males plus slope constants for the regression equations. Linear regression equations for any of the twenty-three different measures were infered by way of the following formula:

$$\hat{Y}_i = \bar{Y} + B\ (X_i - \bar{X})$$

where $\hat{Y}_i$ = predicted value for the ith individual ($i = 1, 2, \ldots, 20$) at twenty years of age

$\bar{Y}$ = mean at twenty (from Björk and Palling's study)

B = slope constant (from Björk and Palling's study)

X_i = twelve year value for the ith individual from the present study

$\bar{X}$ = mean at twelve (from Björk and Palling's study)

Also included in Björk and Palling's data are correlation coefficients for the twenty-three measurements examined. These will be compared with the correlation coefficients obtained from data of the present study. A definition of the pertinent landmarks and anatomical planes employed by Björk and Palling may be found in Appendix II.

Johnston

Johnston's report (1968) contains multiple linear regression equations for males and females at ages seven and twelve, as well as for other age groups. These equations, in some instances, contain more than one independent variable in an attempt to account for a greater proportion of the variability in a particular dependent variable. See Appendix III for a chart of Johnston's equations for males, the equations which will be validated here. A definition of the measures pertinent to this study employed by Johnston are

included in Appendix IV.

Maj and Luzi

Maj and Luzi presented the results of their study in 1964, and it contained linear regression equations which would give the predictable amount of relative growth in mandibular length between nine and thirteen years for males and females on the basis of the gonial angle. See Appendix V for the formulas used by Maj and Luzi to calculate the coefficient of linear regression, increments in mandibular length, and the previously mentioned regression equations. Appendix VI contains the landmarks and measures employed by Maj and Luzi.

Meredith

Meredith (1958) presented findings from a longitudinal study of males from ages five to eleven; the results (correlation coefficients) may be found in Appendix VII. Appendix VIII contains the landmarks and measuring planes employed by the author. The author did not publish regression equations.

Although nose height and face depth were secured by roentgenographic methods, head length was obtained by direct measurement. This made it necessary to

correct the measurements of head length taken directly from roentgenograms to compensate for enlargement; however, skin thickness was taken into account during the tracing procedure. Since the target-film distance varies on the Broadbent-Bolton cephalometer, each measurement was multiplied by a different correction factor, according to the midline-lateral cassette distance (ML), in order to correct for enlargement. See Appendix IX for a table of ML distances and their associated enlargement factors.

Statistical Methods

To test the practical value of the prediction equations the following statistics were employed:

1. Means and and standard deviations--to indicate the amount of variability in each group.

2. The coefficient of correlation (r*)--to determine the degree of linear relationship between actual and predicted values. In this study r* will be employed to delinate correlation coefficients obtained in the process of validation. However, with respect to Meredith's study, r* will represent correlation coefficients calculated only from the data of the present study. These correlation coefficients will then be compared with those obtained by Meredith.

3. The coefficient of determination (r^2)--represents the proportion of the variability of Y which is accounted for by the regression equation. In this study, r^{2*} will be used to indicate coefficients of determination derived from r*.

4. Fisher's Z coefficient (Z)--because of deviations from normality of the sampling distribution of r, Fisher has developed this statistic by which an obtained r can be transformed to Z, a statistic which has a symmetrical sampling distribution even when N is small. The formula for Z is (Snedecor, 1967):

$$Z = \tfrac{1}{2} \log_e [(1 + r) - \log_e (1 - r)]$$

5. Absolute Ƶ (Ƶ ratio)--to test the hypothesis that values of r and r* are drawn at random from the same population. Each was converted to Z, and the ratio of the difference of the Z's to the standard error of the difference was calculated.

$$Ƶ \text{ ratio} = \frac{Z_1 - Z_2}{\frac{1}{N_1-3} + \frac{1}{N_2-3}}$$

Then Ƶ ratio was converted to P using the table of normal distribution for values of Ƶ.

6. Probability (P)--confidence limits were set at the 95% level ($\alpha = .05$), hence, P must be .050 or less before we can reject the null hypothesis that the

samples are from a common population.

7. Index of forecasting efficiency (E)--the reduction in errors of prediction by reason of correlation between two variables.

$$E = 1 - \sqrt{1 - r^{2*}}$$

8. Standard error of the estimate (S.E.Y)--gives, when compared to the standard deviation, an estimate of the reduction in error of prediction when there is knowledge of correlated measurements as compared to errors without knowledge of these measurements.

$$S.E.Y = S.D._y \sqrt{1 - r^{2*}}$$

9. Coefficient of reliability (r_{xx})--measures the extent of linear correlation between double-determinations taken for one subject in ten as an error study. This statistic (according to Johnston, 1968) represents the maximum linear correlation possible for the prediction equation as well as the reliability of tracing and measuring procedures.

10. Confidence intervals--were calculated for Björk and Palling's measure ss-n-sm (ANB) and Johnston's measure $\underline{A}/\overline{B}$. Since α was fixed at .050, the response of a single patient can be expected to be "captured" within the confidence interval 95 times out of 100. Confidence intervals were calculated using the following formula:

$$Y \pm t_{1-\alpha/2}\, Sy/\hat{Y} \sqrt{1 + \frac{1}{50} + \frac{(\hat{Y}_i - \bar{\hat{Y}})^2}{(N-1)\ (S.D.\hat{Y}_i)^2}}$$

V. FINDINGS

Björk and Palling

A comparison of the means and standard deviations from Björk and Palling's study and the present study shows a great deal of similarity (see Table 4). The coefficients of correlation obtained in the process of validating Björk and Palling's equations ranged from .576 to .882 and were extremely high for most measures, except those which involve maxillo-mandibular relationship, numbers 8, 10, and 13 (see Table 5). The coefficients of determination ranged from .332 to .778 and, again, are lowest for those measures involving maxillo-mandibular relationships. Upon converting the r* values to Z (via Z transformation) and calculating the Z ratio and probability, we find the null hypothesis that the samples are drawn from a common population must be rejected at a confidence level of 95% for four of the measures. Three of these involve maxillo-mandibular relationships; the other involves the occlusal plane.

E values ranged from .183 to .529; hence, the reduction in standard error of prediction ranged from 18.27% to 52.88% less than the error of prediction would have been with only an estimate of the mean of the

TABLE 4

A COMPARISON OF MEANS AND STANDARD DEVIATIONS
(BJÖRK AND PALLING'S VERSUS VALIDATION STUDY)

Measurement	Björk & Palling Mean 12	Björk & Palling SD 12	Validation Study Mean 12	Validation Study SD 12	Björk & Palling Mean 20	Björk & Palling SD 20	Validation Study Mean 20	Validation Study SD 20
Angular (degrees)								
1. pr-n-ss	2.30	0.90	1.01	.774	2.30	1.00	1.16	.578
2. id-n-pg	1.20	1.40	-.70	1.385	.09	1.70	-.16	1.324
3. CL-ML	68.20	5.40	68.56	6.004	65.40	6.40	66.82	6.047
4. IL_s-OL	57.80	4.60	55.65	5.279	60.30	4.70	59.90	6.166
5. IL_s-NL	110.50	6.00	109.68	6.917	111.20	6.40	109.82	7.056
6. IL_i-OL	70.30	6.30	71.61	7.079	69.80	6.60	70.00	8.219
7. IL_i-ML	92.10	6.70	94.03	6.766	90.50	7.20	93.83	8.796
8. ss-n-pg	2.50	2.60	4.40	2.147	1.30	3.00	2.79	2.041
9. ss-n-sm	3.40	2.30	5.62	1.742	2.70	2.60	4.18	1.846
10. OL-ss-sm	92.60	4.50	89.75	3.145	91.50	4.60	89.17	3.861
11. n-ss-pg	173.80	5.30	170.03	4.642	177.70	6.10	174.13	4.273
12. s-n-ss	81.30	3.30	82.91	3.514	82.00	3.70	83.06	3.579
13. s-n-sm	77.80	3.30	77.33	2.486	79.30	3.70	79.02	2.985
14. s-n-pg	78.80	3.30	78.46	2.454	80.70	3.90	80.69	3.201
15. IL_s-IL_i	128.10	8.30	127.37	10.500	130.10	9.00	129.92	11.828
Linear (mm.)								
16. (ar-pgn)-(ar-ss)	19.90	4.00	14.49	3.049	27.80	4.90	21.39	4.861
17. (ar-sm)-(ar-ss)	8.00	3.20	5.71	2.135	12.50	4.00	9.31	3.611
18. ar-ss	83.40	4.00	89.62	4.219	91.40	4.60	97.22	4.007
19. ar-sm	91.40	4.50	95.32	4.799	103.90	5.40	106.53	5.757
20. ar-pgn	103.30	5.10	104.10	5.363	119.20	6.00	118.61	6.536
21. pm-ss	48.10	2.60	50.47	3.123	52.70	2.90	55.28	2.561
22. pm-NSP	13.90	2.70	16.39	4.133	13.80	3.30	16.34	4.747
23. pgn-cd	110.40	4.90	107.91	5.739	127.60	5.90	122.32	6.020

TABLE 5

A SUMMARY OF THE STATISTICS OBTAINED IN VALIDATING BJÖRK AND PALLING'S STUDY

Measurement	Björk and Palling N=243			Validation Study N=50		
	r	r^2	Z	r*	r^{2}*	Z
Angular (degrees)						
1. pr-n-ss	.65	.423	.775	.638	.407	.755
2. id-n-pg	.83	.689	1.188	.868	.753	1.325
3. CL-NL	.86	.740	1.293	.818	.669	1.151
4. IL_s-OL	.66	.436	.793	.799	.639	1.096
5. IL_s-NL	.76	.578	.996	.731	.534	.932
6. IL_i-OL	.68	.462	.829	.814	.663	1.139
7. IL_i-ML	.83	.689	1.188	.872	.760	1.341
8. ss-n-pg	.87	.757	1.333	.661	.438	.795
9. ss-n-sm	.86	.740	1.293	.576	.332	.656
10. OL-ss-sm	.86	.740	1.293	.629	.396	.739
11. n-ss-pg	.88	.774	1.376	.588	.345	.675
12. s-n-ss	.91	.828	1.528	.825	.681	1.173
13. s-n-sm	.90	.810	1.472	.810	.655	1.127
14. s-n-pg	.89	.792	1.422	.831	.691	1.191
15. IL_s-IL_i	.72	.518	.908	.842	.709	1.228
Linear (mm.)						
16. (ar-pgn)-(ar-ss)	.87	.757	1.333	.661	.438	1.012
17. (ar-sm)-(ar-ss)	.87	.757	1.333	.726	.527	.921
18. ar-ss	.91	.828	1.528	.784	.615	1.055
19. ar-sm	.87	.757	1.333	.882	.778	1.385
20. ar-pgn	.86	.740	1.293	.881	.776	1.380
21. pm-ss	.81	.656	1.127	.640	.410	.758
22. pm-NSP	.86	.740	1.293	.849	.720	1.253
23. pgn-cd	.77	.593	1.020	.753	.566	.980

TABLE 5--Continued

Validation Study
N=50

Z ratio	P	Ho: $\rho = \rho^*$	E	S.E.Y.	r_{xx}	r^2_{xx}
.081	.936		.229	.446	.974	.949
-.546	.582		.503	.658	.994	.988
.566	.569		.425	3.479	.998	.996
-1.207	.230		.399	3.705	.977	.955
.255	.803		.317	4.816	.997	.994
-1.235	.219		.420	4.771	.987	.974
-.610	.549		.510	4.309	.996	.992
2.144	.032	Reject	.250	1.530	.997	.994
2.536	.011	Reject	.183	1.509	.987	.974
2.206	.028	Reject	.223	3.001	.986	.972
2.794	.005	Reject	.191	3.458	.999	.998
1.414	.159		.435	2.021	.986	.972
1.375	.171		.413	1.753	.948	.899
.920	.358		.444	1.779	.988	.976
-1.275	.204		.461	6.380	.991	.982
1.279	.201		.335	3.232	.998	.996
1.643	.101		.312	2.483	.941	.885
1.885	.060		.380	2.486	.994	.988
-.207	.842		.529	2.713	.990	.980
-.347	.726		.527	3.094	.985	.970
1.470	.142		.232	1.967	.889	.790
.159	.873		.471	2.512	.996	.992
.160	.873		.341	3.966	.978	.956

criterion measure. Again, E values are lowest for measures involving maxillo-mandibular relationships (18.27 to 25.30%). The standard errors ranged from .446 to 6.380 and there did not seem to be any significant distribution for this particular statistic.

Johnston

The means and standard deviations for the sample employed in this particular segment of this study, as well as Johnston's means and standard deviations for future size, may be found in Table 6.

TABLE 6

A COMPARISON OF MEANS AND STANDARD DEVIATIONS (JOHNSTON'S VERSUS VALIDATION STUDY)

Measurement	Johnston		Validation Study			
	Future Size Mean	SD	Mean 7	SD 7	Mean 12	SD 12
$\underline{A}/\overline{B}$	-8.61	3.31	-7.40	3.042	-6.84	3.527
A/B	-0.20	2.44	2.58	2.875	3.07	3.822
e/e	0.39	1.73	.95	1.699	1.35	1.247
∠ Z	1.75	2.99	.47	3.254	3.09	3.330
Prog.	-2.95	3.39	-2.01	3.453	-1.01	4.533

Table 7 contains other statistics which indicate the prediction efficiency of Johnston's equations. In the

TABLE 7

A SUMMARY OF THE STATISTICS OBTAINED IN VALIDATING JOHNSTON'S EQUATIONS

	Johnston N=50			Validation Study N=50									
Measurement	$\bar{R}$	R^2	Z	r^*	r^{2*}	Z	Z ratio	P	Ho: $\rho = \rho^*$	E	S.E.Y	r_{xx}	r^2_{xx}
$\underline{A}/\overline{B}$	.785	.616	1.058	.657	.431	.788	1.313	.190		.246	2.660	.798	.637
A/B	.811	.657	1.130	.393	.155	.415	3.468	.002	Reject	.081	3.514	.915	.837
e/e	.742	.550	.955	.445	.198	.479	2.313	.021	Reject	.104	1.117	.981	.962
$\angle$ Z	.792	.628	1.076	.723	.523	.914	.785	.430		.310	2.299	.958	.918
Prog.	.887	.787	1.408	.788	.621	1.066	1.660	.097		.384	2.791	.976	.953

present sample, validated coefficients of correlation ranged from .393 to .788, while the coefficients of determination ranged from .155 to .621. As in Björk and Palling's study, the aforementioned coefficients, as well as the indexes of forecasting efficiency, were low for those measures involving maxillo-mandibular relationships, A/B and $\underline{A/B}$. The coefficients were also extremely low for e/e. It was thought that since e/e and A/B were based on the natural occlusal plane, a plane which is determined by inspection; perhaps there was some personal, systematic bias in its determination. Higher correlations were found in the angular measures, i.e., $\angle Z$ and Prog., while $\underline{A/B}$ measured parallel to the palatal plane exhibited much higher coefficients than did A/B. Upon examination of the relevant Z ratios, it was found that the null hypotheses were rejected at the 95% confidence level only for A/B and e/e. Accordingly, Johnston retraced the sample employed in the present validation with attention paid only to the location of A, B, $\underline{e}$, $\overline{e}$, and cant of the occlusal plane. The results of this replication may be found in Table 8.

A comparison of values of r^*, r^{2*}, and E obtained for measures involving maxillo-mandibular relationships between Johnston's 1968 study and Björk and Palling's study, reflect much similarity, i.e., for

TABLE 8

RESULTS OF JOHNSTON'S REPLICATION

	Mean 7	SD 7	Mean 12	SD 12	r*	r^{2}*	Z	Z ratio	P	Ho: $\rho = \rho^{*}$	E	S.E.Y
Johnston's Replication												
A/B	1.01	2.31	.67	3.92	.534	.286	.596	2.592	.001	Reject	.155	3.313
e/e	.66	1.61	.58	1.98	.601	.361	.695	1.262	.208		.200	1.583
Validation Study												
A/B	2.58	2.88	3.07	3.82	.393	.155	.416	3.468	.001	Reject	.081	3.514
e/e	.95	1.70	1.35	1.25	.445	.198	.479	2.313	.021	Reject	.104	1.117

Björk and Palling's measure ss-n-sm a correlation coefficient of .576, coefficient of determination of .332 and an index of forecasting efficiency of .183 were obtained, while for Johnston's study values of .657, .431, and .246 respectively were obtained for the measure $\underline{A}/\overline{B}$. Confidence intervals for these two measures may be found in Figures 1 and 2.

Maj and Luzi

Table 9 contains means and standard deviations for Maj and Luzi's sample as well as the sample employed in this validation study.

TABLE 9

A COMPARISON OF MEANS AND STANDARD DEVIATIONS (MAJ AND LUZI'S VERSUS VALIDATION STUDY)

	Maj and Luzi		Validation Study	
	Mean	SD	Mean	SD
Relative Increment In Mandibular Length	9.230	1.955	9.523	2.382

The means of the two samples are quite similar; however, the standard deviation was somewhat higher in the present study. Maj and Luzi based their regression equations on a sample size of twenty-eight and obtained a coefficient of correlation of .673 and a coefficient

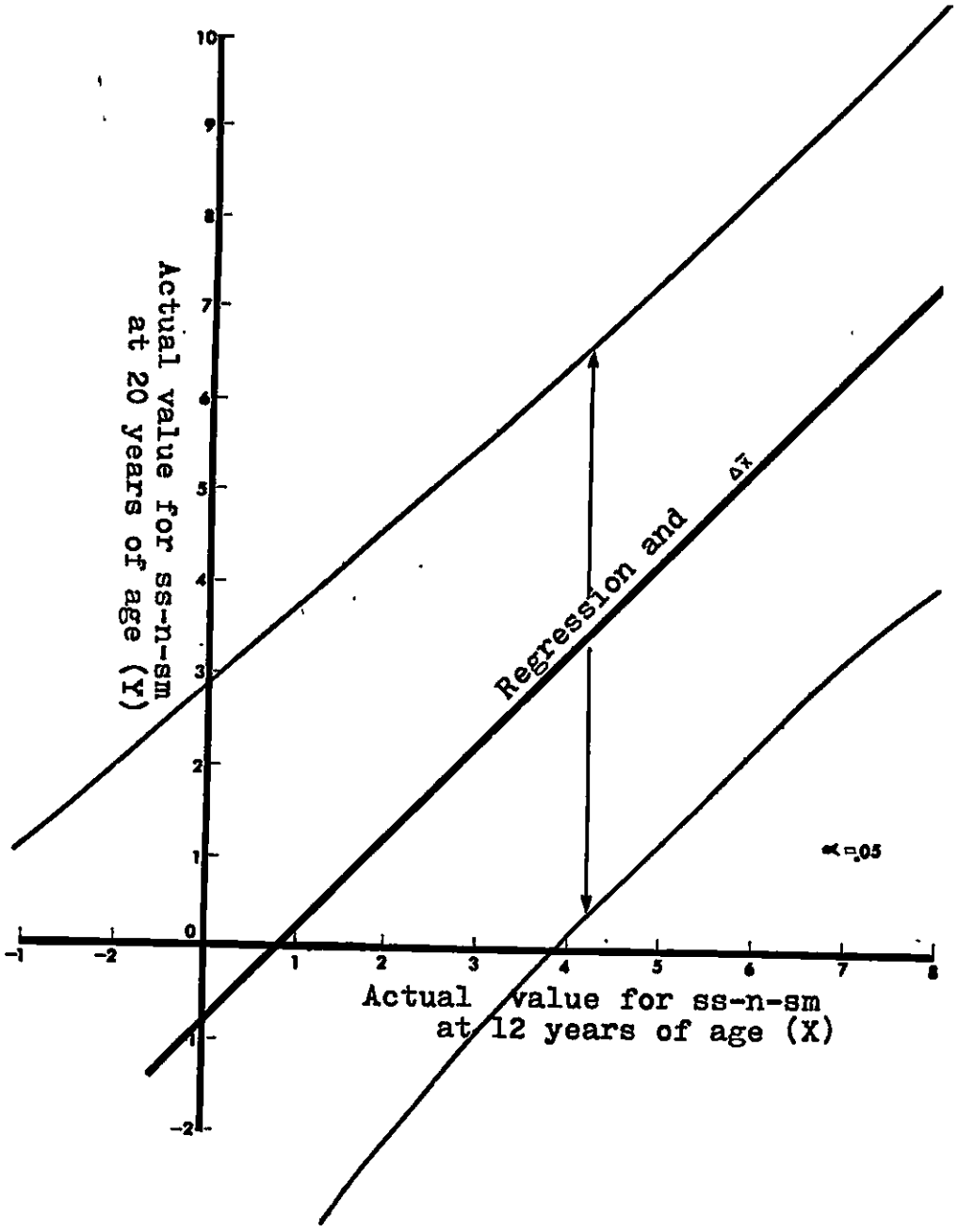


Figure 1--Confidence intervals for the prediction of ss-n-sm; Björk and Palling's regression equation versus assumption of mean change for the prediction of a single (Y), given (X).

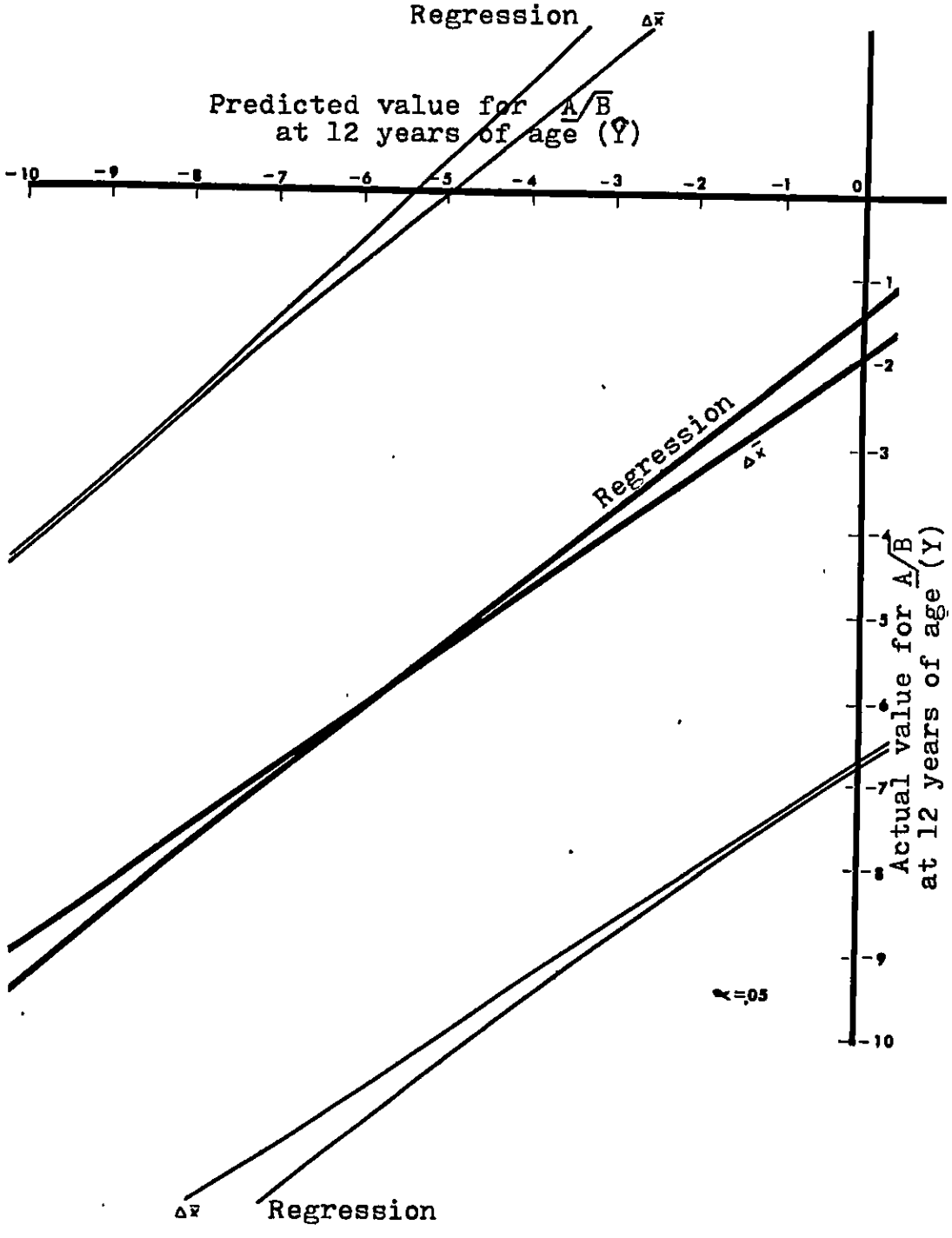


Figure 2--Confidence intervals for the prediction of A/B, Johnston's multiple regression equation versus assumption of mean change for a single individual.

TABLE 10

A SUMMARY OF THE STATISTICS OBTAINED IN VALIDATING MAJ AND LUZI'S EQUATIONS

	Maj and Luzi N=28			Validation Study N=50									
	r	r^2	Z	r*	r^{2*}	Z	Z ratio	P	Ho:$\rho=\rho^*$	E	S.E.Y	r_{xx}	r^2_{xx}
Relative Increment In Mandibular Length	.673	.453	.816	.126	.016	.126	2.795	.005	Reject	.008	2.363	.596	.355

of determination of .453 (see Table 10). Upon validating their equations, a coefficient of correlation of .126 and a coefficient of determination of .016 were obtained. The null hypothesis that these two samples are from a common population must be rejected. A value for E of .008 and 2.363 for S.E.Y are not statistically significant.

Meredith

Means and standard deviations from the validation study for three measurements employed by Meredith are in Table 11.

TABLE 11

MEANS AND STANDARD DEVIATIONS OBTAINED FROM SAMPLE USED IN VALIDATING MEREDITH'S STUDY

Measurement	Validation Study	
	Mean	SD
Nose Height		
Absolute	7.74	2.011
Relative	18.15	4.560
Face Depth		
Absolute	8.39	3.085
Relative	10.41	3.979
Head Length		
Absolute	7.37	2.493
Relative	4.04	1.421

Unfortunately, Meredith did not publish means or standard deviations for his study.

Correlation coefficients and coefficients of determination obtained in the present study were extremely low as were the indexes of forecasting efficiency. See Table 12 for a complete listing of all statistics.

Error Study

The coefficients of reliability (r_{xx}) as well as coefficients of determination (r^2_{xx}) are included in Tables 5, 7, 10, and 12. These values, according to Johnston (1968), are an estimate of the maximum extent of valid linear correlation and proportion of predicted variability possible, since it is unlikely that any measurement could be predicted more accurately than it could be traced. All values appear to be quite acceptable (r_{xx} greater than .90) except for the sample employed in validating Maj and Luzi's regression equations, where a coefficient of reliability of .596 was obtained for the relative increment in mandibular length; however, for the measures of mandibular length and gonial angle, r_{xx} values of .935 and .999 respectively were obtained.

TABLE 12

A SUMMARY OF THE STATISTICS OBTAINED IN VALIDATING MEREDITH'S STUDY

	Meredith				Validation Study										
	r	N	r^2	Z	r*	N	r^2*	Z	Z ratio	P	Ho: $\rho = \rho^*$	E	S.E.Y	r_{xx}	r^2_{xx}
Nose Height															
Absolute	-0.030	57	.001	-.030	.194	50	.038	.196	-1.138	.254		.019	1.963	.972	.945
Relative	-0.350		.123	-.365	.014		.002	.014	-1.903	.057		.001	4.555		
Face Depth															
Absolute	0.130	57	.017	.131	-.201	50	.040	-.204	1.683	.093		.020	3.022	.965	.931
Relative	0.020		.0004	.020	-.308		.095	-.319	1.703	.089		.049	3.786		
Head Length															
Absolute	-0.090	100	.008	-.090	-3.806	50	.145	-.401	1.758	.080		.075	2.306	.995	.990
Relative	-0.280		.078	-.288			.232	-.526	4.597	.0002	Reject	.124	1.245		

VI. DISCUSSION

The application of regression equations to other samples (validation) is a very necessary procedure before any equation can be universally applied and accepted as a true prediction equation. In general, when a regression equation is calculated from one sample and then applied to another, there will be some diminution in predictive accuracy due to random error and sampling variability.

Björk and Palling

At first glance, many of the regression equations of Björk and Palling seem to be relatively accurate; however, the question of the usefulness of these equations must be raised. The measures involving sagittal jaw relation, sagittal apical base relation, and profile angle are clinically most useful to the orthodontist; unfortunately, it is these particular measures which yielded the lowest values for r^*, r^{2*}, and E (Table 5), and it was for these measures that the extent of correlation differed significantly. Measures ss-n-pg, ss-n-sm (ANB), and n-ss-pg, upon validation, yielded correlation coefficients of .661, .576, and .588 as compared to the correlation coefficients from Björk and Palling's original study for the same measures, respectively, of .870, .860, and .880. The

coefficients of determination naturally reflect this same tendency:

	Björk and Palling	Validation Study
ss-n-pg	.757	.438
ss-n-sm	.740	.332
n-ss-pg	.774	.345

Björk and Palling's regression equations accounted for approximately 75% of the variability in these measures for their Swedish sample; however, when applied to the sample obtained from the Bolton Study, their equations accounted for only 37% of the variability in the criterion variables. The following values were obtained for the index of forecasting efficiency:

ss-n-pg = .2503 or 25.03%
ss-n-sm = .1827 or 18.27%
n-ss-pg = .1907 or 19.07%

Thus, the use of specific regression equations provided standard errors which were about 20% smaller than those based upon the assumption that the future mean would be achieved by the individual. Furthermore, the regression equation of Björk and Palling for ss-n-sm was no more accurate than an assumption that the mean change would be achieved by the individual (see Figure 1). This is true for all simple regression equations, they give different measures than an assumption of mean

change, but the confidence intervals are the same regardless of the method employed. Equations that account for approximately 37% of the variability and only reduce the error in prediction by approximately 20% are hardly worth the effort, when orthodontically induced changes (up to 8.0 mm. in A point reported by Ricketts, 1960) are so large in proportion. Moreover, the equations presented by Björk and Palling cover males ranging in age from twelve to twenty years; how often does the orthodontist care to predict what the individual in question at age twelve will look like at age twenty? Obviously then, these regression equations, which are difficult to apply and do not reduce standard errors any more than an assumption of mean change, do not merit use by a clinical orthodontist.

Johnston

The equations published by Johnston are multiple linear regression as opposed to the simple linear regression equations published by Björk and Palling and Maj and Luzi. Upon examination of Table 7, we see that prediction efficiency was greatest for measures Prog. and $\angle$ Z, which are clinically not very useful (except perhaps in cases involving clefts) and low for measures $\underline{A}/\overline{B}$, A/B, and e/e which involve maxillo-mandibular

relation and are clinically quite useful. The measure $\underline{A}/\overline{B}$, (measured parallel to the palatal plane) exhibited a smaller diminution in r* when validated than did measure A/B measured parallel to the occlusal plane. Apparently this is due to the unreliability of the natural occlusal plane, since the measure e/e was also affected. In order to test the hypothesis that there was some personal bias in establishing the occlusal plane, Johnston volunteered to retrace the 100 cephalograms employed in validating his study and to reestablish the occlusal planes, in order to determine the possible effect upon measures A/B and e/e; the results are in Table 8. From this table it becomes evident that the hypothesis concerning the personal bias in establishment of the natural occlusal plane is indeed correct, since higher correlation coefficients, as well as coefficients of determination, index of forecasting efficiency, etc. were obtained from the replication. This may be construed as a testimonial to Johnston's tracing accuracy; however, the standard deviations for both samples are quite similar, hence, the conclusion that since Johnston calculated the original equations, they work better when he uses them.

It is felt by the author that the technique

employed by Johnston (multiple linear regression) holds the greater degree of promise for a viable prediction scheme, since an r* value for $\underline{A}/\overline{B}$ of .657 was obtained as opposed to a value for ss-n-sm of .576 for Björk and Palling's study. At first glance this difference does not seem to be meaningful; however, Johnston's equations cover the more clinically useful age groups of four and nine, five and ten, six and eleven, seven and twelve, and eight and thirteen as compared to Björk and Palling's age group of twelve and twenty. Johnston also published equivalent regression equations for females, which appear to be even more accurate and reliable than those published for males. In light of this fact, perhaps a future validation study should be performed testing the prediction efficiency of equations for the various age groups in males and females, since it is possible that the group examined in this study, seven and twelve year old males, may be more variable and hence more difficult to predict than the female groups or other male groups. Again it is felt that, of all those examined, $\underline{A}/\overline{B}$ is the only measure which is significantly reliable and of sufficient clinical usefulness to merit further validation; however, we must remain cognisant of the fact that Johnston's

prediction equation for $\underline{A}/\overline{B}$ accounted for only about 43% of the variability (r^{2*} = .431) and reduced the error of prediction by approximately 25% (E = .246) over an assumption that the future mean would be achieved by the individual. Furthermore, if an assumption of mean change in measure $\underline{A}/\overline{B}$ is made, confidence intervals approximately equal to those derived using Johnston's multiple regression equation are obtained (see Figure 2).

The regression equations of Johnston did, however, exhibit a smaller decrease in accuracy than those of Björk and Palling, in spite of the fact that Johnston employed a smaller sample size, 90 versus 243 for Björk and Palling's study. Björk and Palling obtained a coefficient of correlation for ss-n-sm (ANB) of .860, and this diminished to a value of .576 for this study. On the other hand, Johnston obtained a value for $\underline{A}/\overline{B}$ of .785 and this diminished only to .657; hence, the conclusion that Johnston's equation for $\underline{A}/\overline{B}$ is more reliable when applied to a different sample than Björk and Palling's equation for ss-n-sm (ANB). It is also more useful since it covers a wider range of age groups, but is no more accurate than an assumption of mean change.

Johnston's equations for A/B and e/e, which are based upon the occlusal plane, are reliable only if he establishes the occlusal plane and are no more accurate than Björk and Palling's equations in the author's hands. Furthermore, Johnston's multiple linear regression equations are more difficult to apply than simple linear regression equations, such as Björk and Palling's, and are not felt to be significantly accurate to in any way constitute a clinically useful prediction scheme.

Maj and Luzi

The prediction equations published by Maj and Luzi yielded very low correlation coefficients (r*) and coefficients of determination (r^{2*}) upon validation, i.e., the r* value decreased to .126 from .673 while the value for r^{2*} went from .453 to .016 (see Table 10). The validated index of forecasting efficiency was .008 or .80%; hence, the error of prediction (sample dispersion) was diminished by 0.80% by the use of Maj and Luzi's prediction equations. Moreover, the coefficient of reliability was fairly low, .596; however, this was recorded for the relative increment in mandibular length. The coefficient of reliability for mandibular length was .935 and for the gonial angle a

coefficient of .999 was obtained, this discrepancy was due to the fact that Maj and Luzi calculated percentage increments in mandibular length using a formula given by Nanda:

$$\frac{Y_2 - Y_1}{\frac{Y_1 + Y_2}{2}} \times 100$$

where Y_1 and Y_2 are the values at the beginning and end of the time period

By multiplying mandibular increments by 100 the error present was magnified, resulting in far less reliability than if the authors had just calculated the increment in mandibular length between age nine and thirteen.

In the final analysis, this prediction scheme is extremely unreliable, possibly because of a small sample and the calculation of relative rather than absolute increments in mandibular length. The prediction equations lost a great deal of accuracy when applied to a different sample, but perhaps an Italian population behaves differently than Ohio families with respect to mandibular growth increments. Furthermore, these equations attempt to predict something which seems clinically irrelevant, i.e., relative increment in mandibular length, according to Johnston (1968) even if this was predicted with 100% accuracy we would still be left with the problems of direction of mandibular

growth and maxillo-mandibular relation. One wonders if the prediction of clinically useless measures is a step forward or a step backward.

Meredith

Since Meredith did not publish regression equations for his study, it was possible only to compare correlation coefficients and coefficients of determination from his study with those from this study. Upon examining Table 12, one can readily see that there is little or no statistically significant association between magnitude of nose height, face depth, or head length at age five years and absolute increment during the ensuing six years. For relative increments there is little statistical significance between nose height and face depth at age five and the same measures at age eleven; however, for head length the null hypothesis can be rejected at a high level of confidence. Thus, we can infer that there is low negative relationship between head length at age five and relative increase between five and eleven years. The relationship is not clinically useful, since a coefficient of determination of .232 and an index of forecasting efficiency of .124 were obtained. In the final analysis, the measures nose height, face depth, and head length were so weakly

correlated with absolute and relative increases between five and eleven years of age, that to publish the regression equations would probably have served no useful purpose and might easily be misconstrued as an attempt at growth prediction.

Error

The values of r_{xx} and r^2_{xx} calculated indicate that coefficients of correlation greater than .960 and coefficients of determination greater than .922 are difficult to attain (these figures represent mean values for all four groups). This would appear to be the maximum degree of accuracy possible (according to Johnston, 1968), since it is impossible to predict more accurately than a cephalogram can be traced. Another source of error in the cephalometric technique is the proper positioning of the patient in the cephalostat consistently.

There is still another aspect to be considered in regards to cephalometric prediction, and that is the estimation of orthodontically induced changes for each individual orthodontist. Orthodontic treatment usually involves a two year time period; however, the changes induced in the craniofacial complex are quite large (i.e., Ricketts (1960) has reported 8.0 mm. changes in

point A) and failure to account for this orthodontically induced variability would severly decrease the accuracy of any method of growth prediction. If, on the other hand, one were able to predict with some degree of accuracy the changes wrought by treatment, then the accuracy of prediction would be significantly increased.

Summary

Upon validating a variety of regression equations and correlation coefficients derived from growth studies by Björk and Palling, Meredith, Johnston, and Maj and Luzi, a diminution in predictive accuracy was observed universally. The diminution in predictive accuracy was statistically so large in the case of Meredith's correlation coefficients and Maj and Luzi's regression equations that accurate application to another sample is not practicable.

The simple linear regression equations of Björk and Palling, although extremely accurate for many measures, fail to predict changes in maxillo-mandibular relationship with sufficient accuracy to constitute a viable prediction scheme. Furthermore, for measure ss-n-sm the regression equation was no more accurate than an assumption of mean change. The regression equations are also too specific with respect to age to be widely

applicable.

The multiple linear regression equations presented by Johnston, although difficult to apply and in some instances based upon an unreliable plane, hold some degree of promise for a viable prediction scheme, since (1) a smaller decrease in the predictive accuracy of these equations was found upon validation, and (2) they are applicable to various age groups for both males and females. Although Johnston's equations hold the greater degree of promise for a prediction scheme, they do not presently appear to account for a sufficient amount of individual variability to be clinically useful, and in fact for measure $\underline{A/B}$, the multiple regression equation was no more accurate than an assumption of mean change.

In the final analysis, predictable changes in the craniofacial complex occuring as a result of growth are so slight in comparison with changes wrought by orthodontic treatment and inherent errors in the cephalometric technique that the prediction of growth changes, in and of themselves, seems to be a fruitless endeavor.

VII. CONCLUSIONS

1. Björk and Palling's prediction equations do not provide sufficiently accurate predictions for the more important craniofacial measurements to warrant widespread use. Furthermore, the age span from twelve to twenty year old males severly hinders the clinical applicability of these equations.

2. The multiple linear regression equations of Johnston, which are based upon measures involving the occlusal plane, are unreliable; however, the measures based upon the palatal plane are fairly reliable and more useful than Björk and Palling's equations, inasmuch as Johnston's equations cover five age groups from four to thirteen for both males and females.

3. The equations published by Johnston, however, are not felt to be sufficiently accurate to constitute a clinically useful prediction scheme.

4. The prediction scheme of Maj and Luzi was extremely unreliable and of little clinical significance. The accuracy, however, might have been increased somewhat had the authors calculated absolute, rather than relative increments in mandibular length.

5. Meredith's correlation coefficients augured no clinically useful relationships between head length, nose depth, or face height at age five and absolute or relative increase in the same measure during the ensuing six years.

6. Contemporary methods of cephalometric prediction are incapable of accurately estimating clinically meaningful changes in the craniofacial complex which occur only as a consequence of growth.

7. Predictable changes in the craniofacial complex occuring as a result of growth are so slight in comparison with changes wrought by orthodontic treatment and inherent errors in the cephalometric technique that the prediction of growth changes, in and of themselves, seems to be a fruitless endeavor.

8. The use of simple regression equations yields different measures than an assumption of mean change; however, the predictions are no more accurate (confidence intervals remain the same).

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APPENDIX I

SUMMARY OF BJÖRK AND PALLING (1955)

Variable	Mean 12	SD 12	Mean 20	SD 20	B 12/20	r 12/20
I. Alveolar prognathy, upper						
1. pr-n-ss	2.3	0.9	2.3	1.0	0.71	0.65
II. Alveolar prognathy, lower						
2. id-n-pg	1.2	1.4	0.9	1.7	0.98	0.83
3. CL/ML	68.2	5.4	65.4	6.4	1.00	0.86
III. Incisal inclination, upper						
4. IL_s/OL	57.8	4.6	60.3	4.7	0.68	0.66
5. IL_s/NL	110.5	6.0	111.2	6.4	0.80	0.76
IV. Incisal inclination, lower						
6. IL_i/OL	70.3	6.3	69.8	6.6	0.71	0.68
7. IL_i/ML	92.1	6.7	90.5	7.2	0.89	0.83
V. Sagittal jaw relation						
8. ss-n-pg	2.5	2.6	1.3	3.0	1.00	0.87
9. (ar-pgn)-(ar-ss)	19.9	4.0	27.8	4.9	1.06	0.87
Sagittal apical base relation						
10. ss-n-sm	3.4	2.3	2.7	2.6	0.77	0.86
11. OL/ss-sm	92.6	4.5	91.5	4.6	0.89	0.86
12. (ar-sm)-(ar-ss) .	8.0	3.2	12.5	4.0	1.09	0.87

APPENDIX I--Continued

Variable	Mean 12	SD 12	Mean 20	SD 20	B 12/20	r 12/20
Profile angle						
13. n-ss-pg	173.8	5.3	177.7	6.1	1.00	0.88
Prognathic angles						
14. s-n-ss	81.3	3.3	82.0	3.7	1.00	0.91
15. s-n-sm	77.8	3.3	79.3	3.7	1.00	0.90
16. s-n-pg	78.8	3.3	80.7	3.9	1.00	0.89
Inclination of upper to lower incisors						
17. IL_s/IL_i	128.1	8.3	130.1	9.0	0.77	0.72
Facial radii						
18. ar-ss	83.4	4.0	91.4	4.6	1.00	0.91
19. ar-sm	91.4	4.5	103.0	5.4	1.00	0.87
20. ar-pgn	103.3	5.1	119.2	6.0	1.00	0.86
Jaws						
21. pm-ss	48.1	2.6	52.7	2.9	0.92	0.81
22. pm to NSP	13.9	2.7	13.8	3.3	1.05	0.86
23. pgn-cd	110.4	4.9	127.6	5.9	0.93	0.77

Determinations no.: 9, 12, 18, 19, 20, 21, 22, 23 are expressed in millimeters, all others in degrees.

APPENDIX II

MEASURING POINTS EMPLOYED IN BJÖRK AND PALLING'S STUDY (1955, p. 204-206)[1]

Measuring points:

ARTICULARE (ar): point at the junction of the contour of the external cranial base and the dorsal contour of the condylar processes.

BASION (ba): the perpendicular projection of the anterior border of foramen magnum (endobasion) on a tangent through the lower margin of the foramen.

CONDYLION (cd): the top of the condylar head.

GNATHION (gn): the lowest point on the symphysis of the mandible.

GONIAL TANGENT POINT (tgo): the junction of the basal tangent and the ramal tangent of the mandible.

GONION (go): a point on the bony contour of the gonial angle located by bisection of the angle formed by the mandibular base line and the ramal line.

INCISION INFERIUS (ii): the midpoint of the incisal edge of the more prominent lower central incisor.

INCISION SUPERIUS (is): the midpoint of the incisal edge of the more prominent upper central incisor. (io): normal projection of incision inferius on the occlusal line.

INFRADENTALE (id): the highest and most forward projecting point on the mandibular alveolar process.

MOLARE INFERIUS (mi): the perpendicular projection of the mesial contact point of the lower first permanent molar onto the occlusal line, determined as the mid-point between right and left molars. The position may be transferred to the roentgenogram as the projected arch length, measured from the dental cast from incision inferius to the corresponding bimolar point.

NASION (n): the most anterior point of the naso-frontal suture.

APPENDIX II--Continued

ORBITALE (or): the lowest point on the infraorbital margin.

POGONION (pg): a point on the bony contour of the chin, located by the bisection of the angle formed by the chin line and the mandibular base line.

PROSTHION (pr): the lowest and foremost projecting point of the maxillary alveolar process.

PTERYGOMAXILLARE (pm): a point representing the dorsal margin of the maxilla at the nasal floor level. The point is located on the dorsal contour of the maxilla, upwards forming the anterior border of the pterygopalatine fossa, where it intersects the contour of the hard and soft palates.

SELLA (s): the center of the bony crypt forming the sella turcica. The surface of the sella turcica is determined regardless of the contours of the clinoid processes, and is limited upwards by a line from tuberculuum sellae to dorsum sellae. The center is defined as the midpoint of the greatest diameter from the tuberculum sellae.

SPINAL POINT (sp): (Acanthion), the apex of the anterior nasal spine.

SUBSPINALE (ss): the most posterior point on the outer contour of the maxillary alveolar process.

SUPRAMENTALE (sm): the most posterior point on the outer contour of the mandibular alveolar process.

Reference lines:

NSL: the nasion-sella line.

NSP: the nasion-sella perpendicular.

NL: the nasal line, through the spinal point and pterygomaxillare.

OL: the occlusal line, through incision superius and the distal cusp summit of the first upper molar, or, when this tooth is missing, the mesial cusp summit of the second upper molar.

APPENDIX II--Continued

CL: the chin line, from infradentale through pogonion.

IL_s: upper incisor axis from is through apex.

IL_i: lower incisor axis from ii through apex.

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[1]The measuring points of Björk and Palling are depicted in Figure 3.

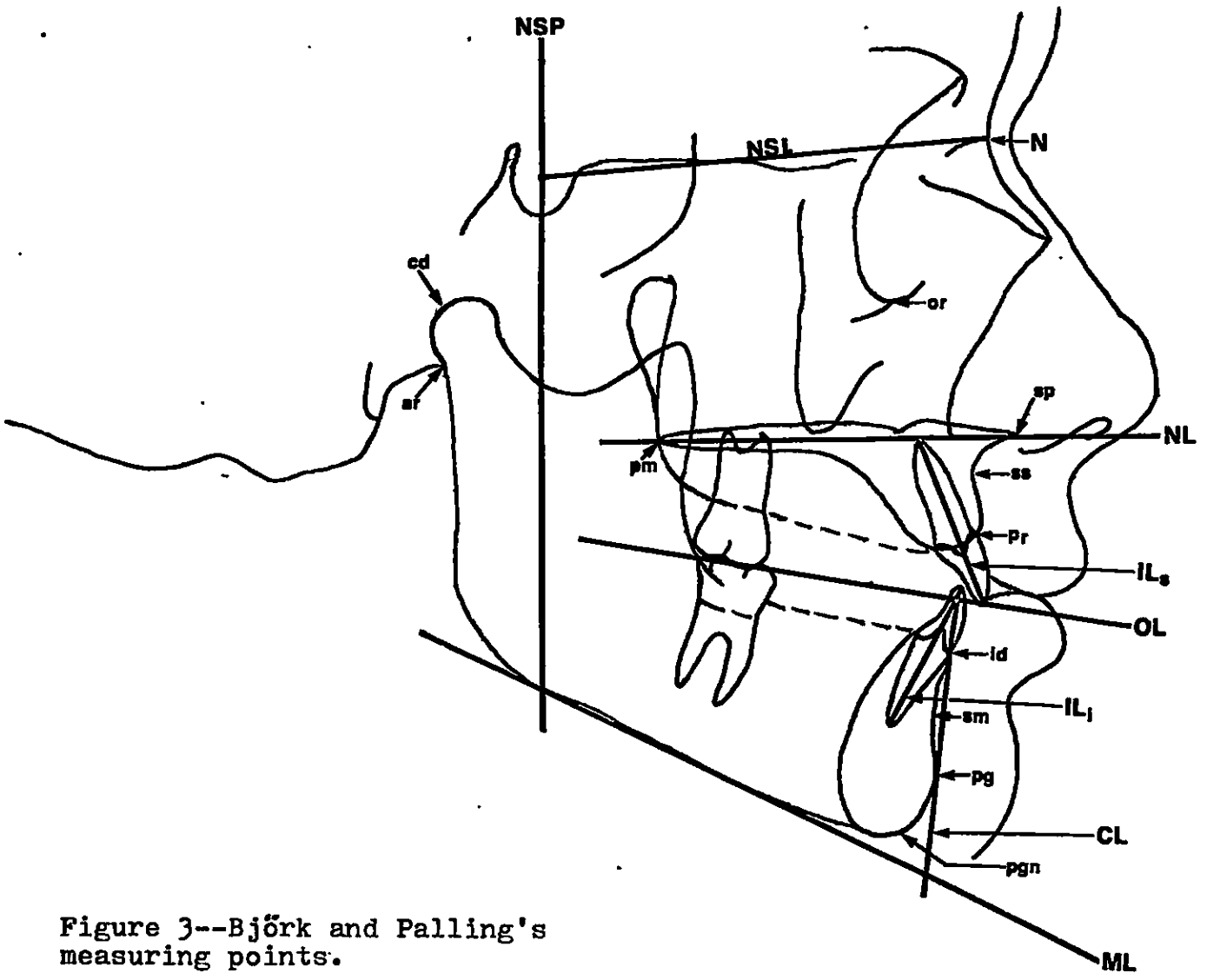


Figure 3--Björk and Palling's measuring points.

APPENDIX III

JOHNSTON'S MULTIPLE REGRESSION EQUATIONS

MALES

	y	$=$	a	$+$	$(b_1 \cdot x_1)$	$+$	$(b_2 \cdot x_2)$	$+$	$(b_3 \cdot x_3)$
Future Size	$\underline{A}/\overline{B}$		12.48		0.84		$\underline{A}/\overline{B}$		-1.49	Sp/Pal.		
	A/B		-0.07		0.88		A/B		0.32	Cp-S	-0.11	∠Ptyg.
	e/e		0.06		0.76		e/e					
	∠ Z		3.12		0.81		∠ Z					
	Prog.		0.89		1.05		Prog.					

APPENDIX IV

MEASURES EMPLOYED IN JOHNSTON'S STUDY[1]

1. Linear Measures

   A. PAL--Palatal Length: A to PNS measured parallel to the palatal plane.

   B. Cp-S--Anteroposterior position of the condyle relative to S: Cp to S, measured parallel to palatal plane.

   C. Prog.--Anteroposterior position of A relative to NA: A to NA, measured parallel to palatal plane. The measure is positive if A is anterior to NA.

   D. $\underline{A}/\overline{B}$--Position of A point relative to B point: $\underline{A}$ to $\overline{B}$, measured parallel to palatal plane.

   E. A/B--Position of A point relative to B point: measured parallel to natural occlusal plane.

   F. e/e--Position of e point relative to B point $\underline{e}$ to $\overline{e}$ measured parallel to natural occlusal plane.

2. Angular Measures

   A. $\angle$ Ptyg.--Pterygoid plane angle: angulation of internal pterygoid process.

   B. $\angle$ Z--Maxillomandibular relation: GN-S-PNS.

   C. Sp--Septal area: area of the closed figure S-NA-A proj.-PNS-S. "A proj." is the intersection of NA-A with palatal plane.

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[1]Johnston's measures are depicted in Figure 4.

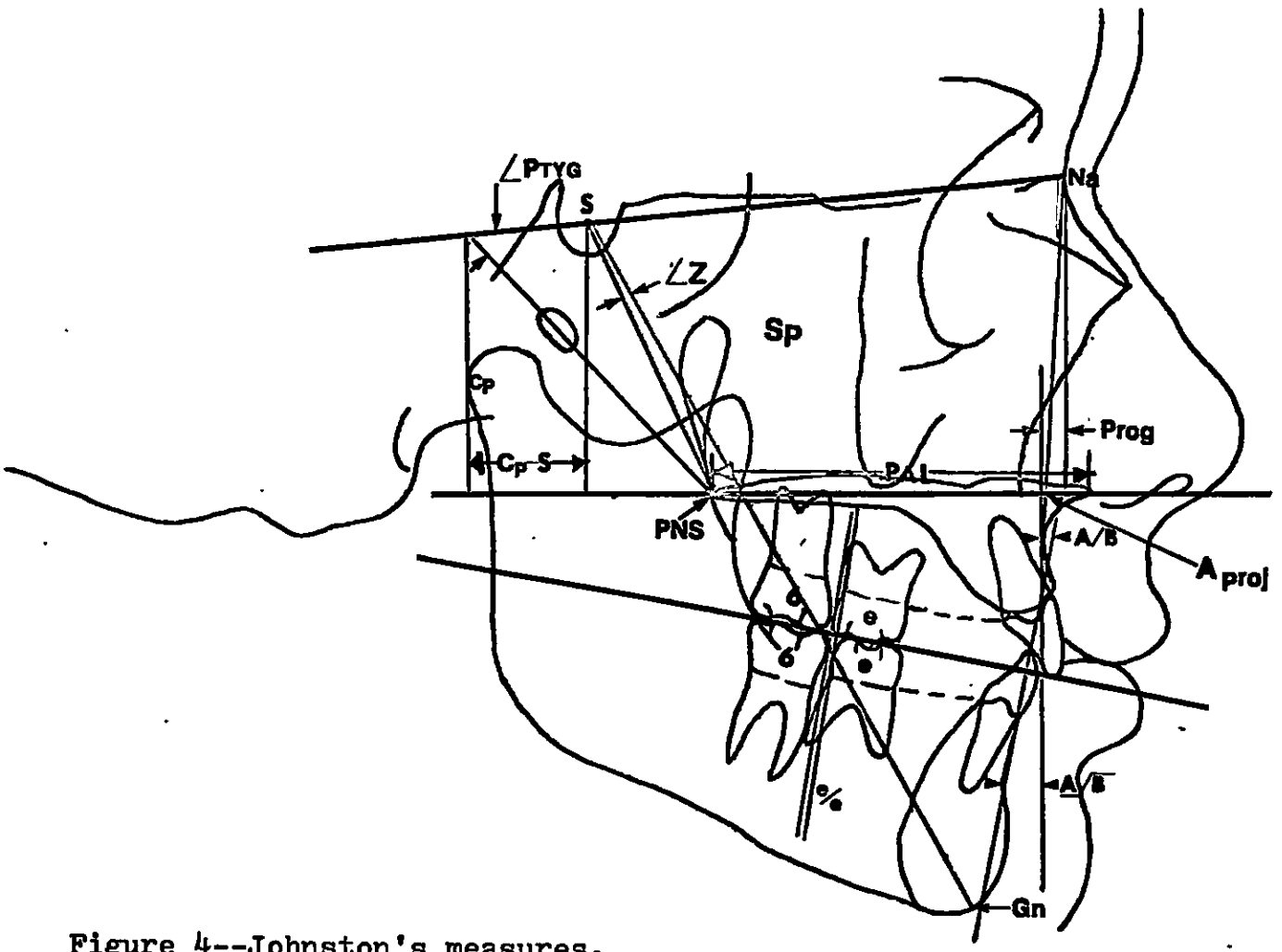


Figure 4--Johnston's measures.

APPENDIX V

FORMULAS EMPLOYED BY MAJ AND LUZI

The coefficient of linear regression was calculated, using the formula:

$$B = \frac{\Sigma (x_i - \bar{x})(y_i - \bar{y})}{\Sigma (x_i - \bar{x})^2}$$

where $(x_i - \bar{x})$ = deviation from the mean of the gonial angle

$(y_i - \bar{y})$ = deviation from the mean of the relative increments of the mandibular length

This calculation made it possible to state, that in the time period considered, the average relative increment in mandibular length is 0.329% for each degree of the gonial angle value.

The average value of the gonial angle, at nine years of age being 125.85°, and the average relative increment in mandibular length from nine to thirteen years being 9.392%.

The formula that gives the predictable amount of relative increment in mandibular length on the basis of the values of the gonial angle, is as follows:

a) when $x > 125.85°$

(1) $y = 9.392 + 0.329 (x - 125.85)$

b) when $x < 125.85°$

(2) $y = 9.392 - 0.329 (125.85 - x)$

APPENDIX V--Continued

where y = relative increment of the mandibular length from nine to thirteen years

x = measure in degrees of the gonial angle at nine years of age level

Percentage increments were calculated using the formula given by Nanda:

$$\frac{Y_2 - Y_1}{\frac{Y_1 + Y_2}{2}} \times 100$$

where Y_1 and Y_2 are the values at the beginning and end of the time period.

APPENDIX VI

MAJ AND LUZI'S LANDMARKS[1]

1. Mandibular Length--distance between the extreme point of the condyle and the point of the chin farthest from it. (Co-M line)

2. Gonion--the most distant position from the Co-M line.

3. Gonial Angle--Co-Go-M.

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[1]Maj and Luzi's landmarks are depicted in Figure 5.

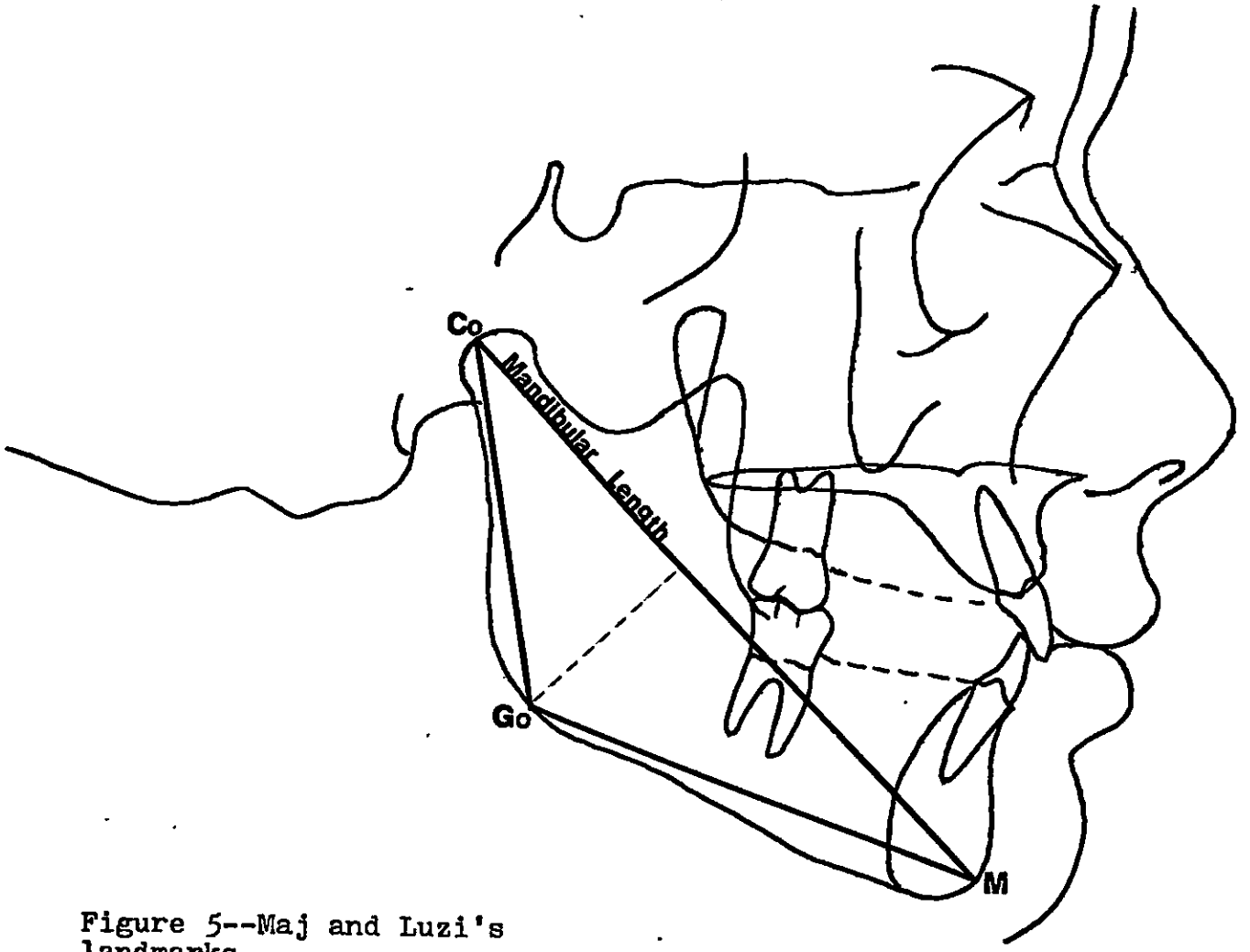


Figure 5--Maj and Luzi's landmarks.

APPENDIX VII

RESULTS OF MEREDITH'S STUDY

Size-Gain (mm)

(Absolute Increase)

x	y	r	Sample Size N
Head Length Age 5	Increase between 5 & 11	-0.09	100
Face Depth Age 5 NA-ANS	Increase between 5 & 11	0.13	57
Nose Height Age 5	Increase between 5 & 11	-0.03	57

Size-Gain (% Increase)

(Relative Increase)

x	y	r	Sample Size N
Head Length Age 5	Increase between 5 & 11	-0.09	100
Face Depth Age 5 NA-ANS	Increase between 5 & 11	0.02	57
Nose Height Age 5	Increase between 5 & 11	-0.35	57

APPENDIX VIII

MEREDITH'S LANDMARKS AND MEASURING PLANES[1]

1. Nose Height--distance from nasion to anterior nasal spine.

2. Face Depth--the distance from a point on the anterior border of the maxilla 0.8cm below the nasal spine to a point representing the anterior-most extension of the occipital condyles.

3. Head Length--glabello-occipital length of the head.

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[1]Meredith's landmarks and measuring planes are depicted in Figure 6.

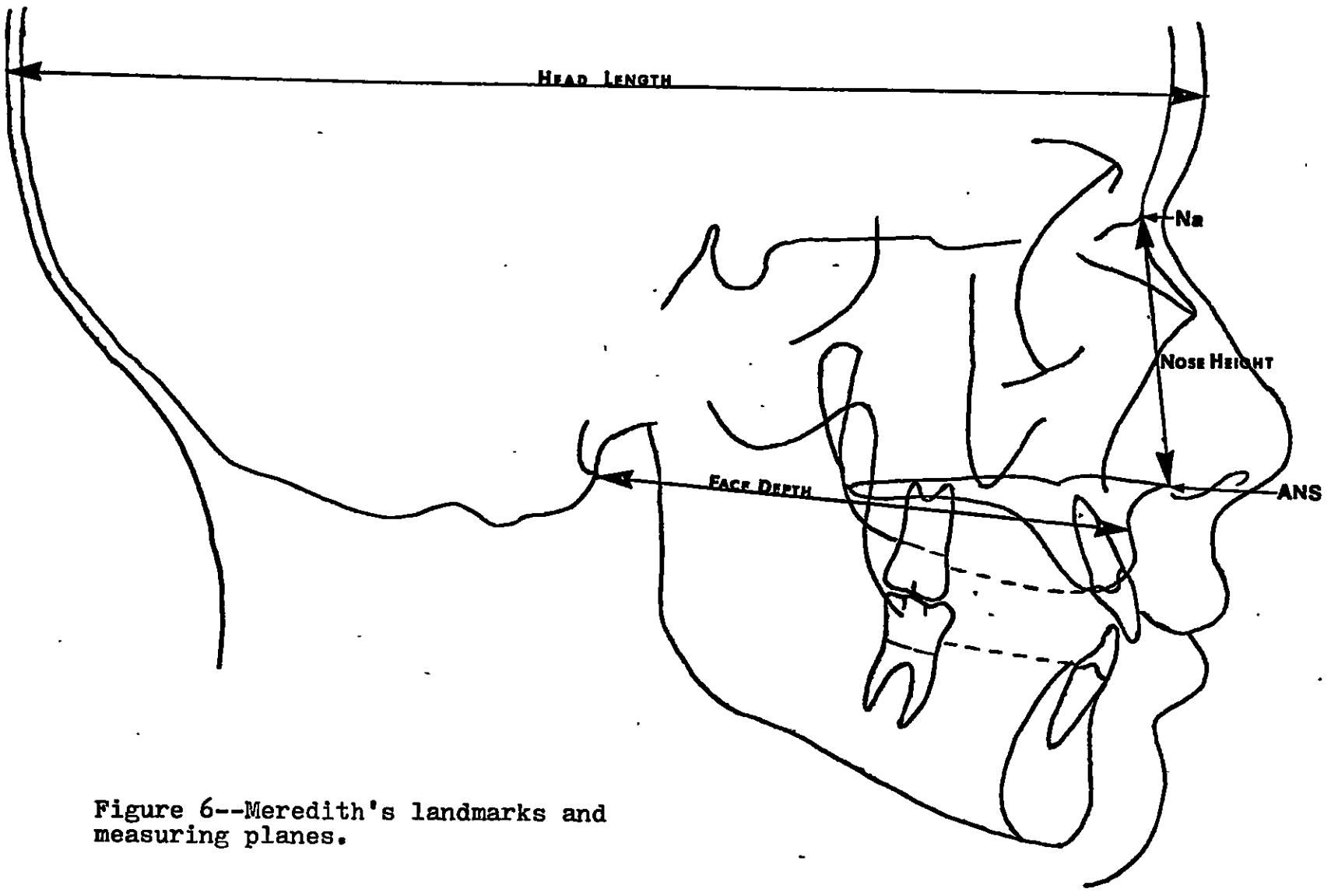


Figure 6--Meredith's landmarks and measuring planes.



APPENDIX IX

ML DISTANCE AND ASSOCIATED ENLARGEMENT

Target Film Distance (ML Distance)	Percentage Enlargement
70	4.6
75	4.9
76	5.0
77	5.0
78	5.1
79	5.2
80	5.2
81	5.3
82	5.4
83	5.4
84	5.5
85	5.6
86	5.6
87	5.7
88	5.8
89	5.8
90	5.9
91	6.0
92	6.0
93	6.1
94	6.2
95	6.2
96	6.3
97	6.4
98	6.4
99	6.5
100	6.6
101	6.6
102	6.7
103	6.8
104	6.8
105	6.9
110	7.2
115	7.6
120	7.9
125	8.2
130	8.5
135	8.9
140	9.2